J

# APPENDIX J

## LDR AM HYBRID LAB TEST PERFORMANCE

**Lucent Digital Radio, Inc.**

**20 Independence Blvd**

**Warren, NJ 07059, USA**

 

## Overview

This appendix documents the results of the lab tests performed on a firmware implementation of LDR AM Hybrid system. Firmware implementations of both transmitter and receiver are based on a system simulation of the entire system using SPW simulator tools. Interference and channel impairment were included in the simulator to be able to tune and predict the performance of the system under different impairment conditions. The real time implementation includes a special GUI interface that allows rapid testing of a wide variety of parameters and functions used to optimize the analog audio quality, control the AM analog modulation index, etc. Those parameters were optimized and fixed for the entire test procedure described in this section. The transmitter prototype was duplicated to allow the generation of three AM Hybrid exciters to simulate two simultaneous interferers.

The test set-up and the methodology were carefully designed to allow repeatable and controlled performance results. In this lab test the focus is on objective performance presented in terms of Frame Error Rates (FER). The FER does not represent directly the audio quality since error concealment techniques mask where errors are detected and add a significant improvement to audio quality.

To simulate in the lab tests the main impairments affecting the coverage and audio quality, LDR tested its AM Hybrid system under a variety of conditions. In this appendix the following tests were performed.

***Performance in AWGN***: this test measures system performance under additive white Gaussian noise.

***Receiver Sensitivity***: this test measures the sensitivity of the receiver to low level signal in a clean channel (no impairments).

***Performance in the presence of interference***: this test measured performance in the presence of co-channel, first and second adjacent AM Analog and AM Hybrid signals.

## Test Set Up and Procedures

### Test set up configuration

The lab test set-up, given in Figure J-1, comprises of three LDR AM Hybrid exciters, a noise generator, a set of attenuators to control signal levels and a single AM Hybrid receiver under test. This set-up was used in all lab tests. The desired AM IBOC signal exciter was in the ON position during all the tests. The setting of the other two AM Hybrid exciters, the Noise/Com generator and the attenuators were chosen according to the specific test.

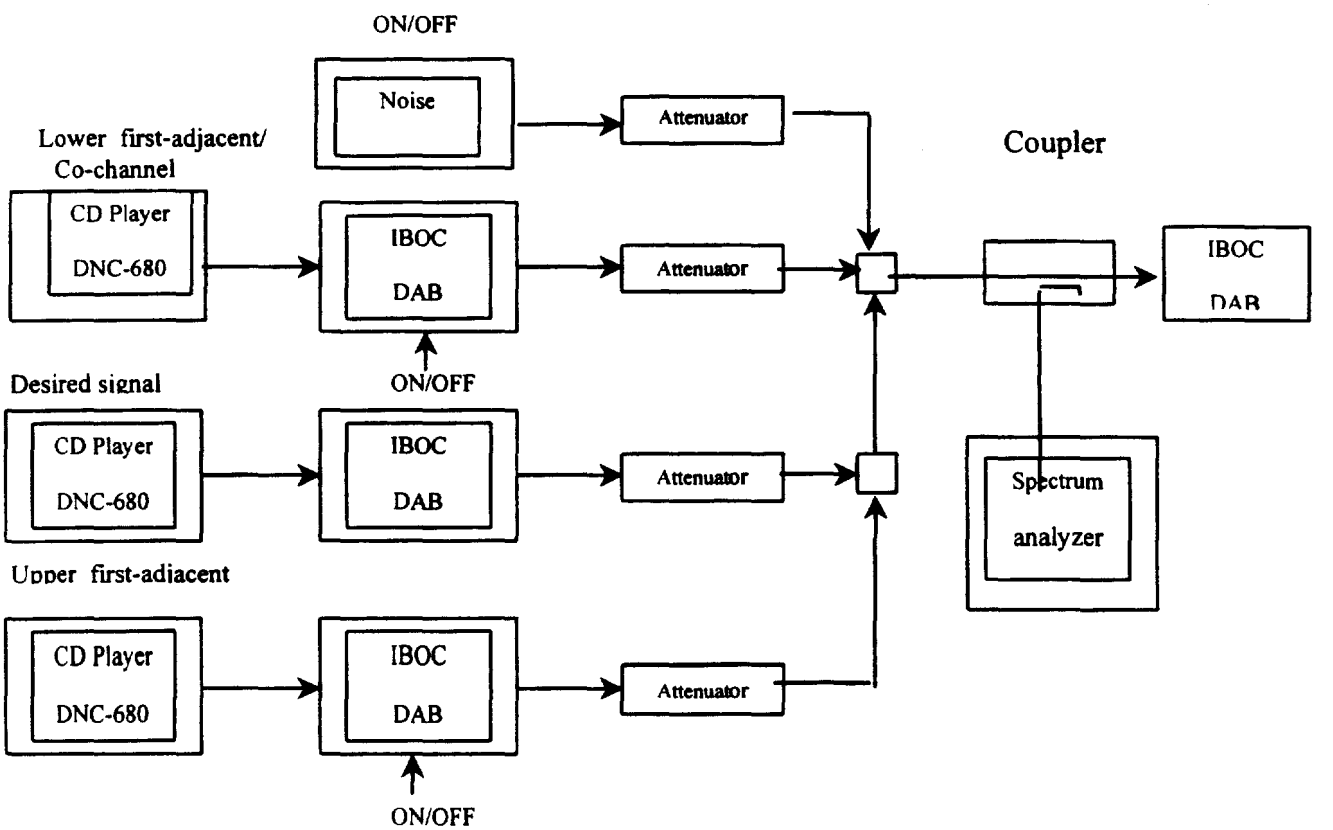


*Figure J-1: AM Hybrid Lab Test Set Up*

## The AM Hybrid Exciter

The desired signal AM IBOC exciter includes an Orban AM audio processor, LDR firmware that generate the hybrid combination of the analog and the digital signal and an I, Q generator, see figure J-2.

In this test set-up the audio signal from the audio compressor is used only to modulate the analog carrier. For this objective test a separate firmware digital random generator is used as input to each one of the three streams. To allow a repetitive test the same audio cut was used in all the tests, the modulation was limited to a bandwidth of +/-4.5 kHz and modulation index was set to 100%.

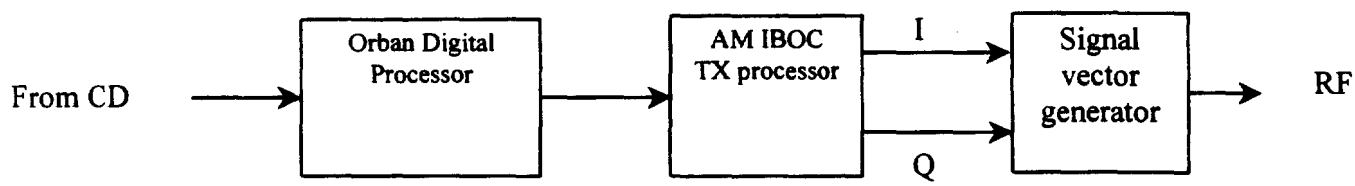


*Figure J-2 AM Hybrid Exciter*

## Performances Criteria

In all the test results presented in this appendix, Frame Error Rate (FER) is used as the threshold of acceptability for the digital audio quality. LDR's FEC process includes a combination of error correction and error detection. The error detection flags from the channel decoder are used by the PAC decoder algorithm to mitigate errors and improve

audio quality for some level of frame errors. The audio quality in LDR's Multi-streaming PAC approach for the AM system is much less sensitive to FER in the left and right streams (enhancement streams) than in the central audio stream (the core stream). However to simplify the presentation of the results to the reader, we are using the same relatively low FER (1%) as threshold for all three streams.
S/N (signal to noise ratio) is used in the AGWN tests, where the signal is the power of the AM carrier and the noise is the power of the noise in 20 kHz bandwidth. Receiver sensitivity tests are given in dBm.

**Test Results**

In this section, test results are presented under different impairment conditions. From the simulation, we knew aprioi the performances of the system under different conditions. Thus, in the lab tests levels were set around the expected results from the simulation.

In LDR's Multi-streaming PAC approach, the three streams are affected differently in the presence of interference, thus the results are given separately for each stream.

Despite the fact that the spectrum of a second adjacent AM IBOC interfere does not overlap with the desired AM IBOC signal, we tested this condition. When both first and second adjacent interferes exist, even a low level second adjacent interfere will significantly affect the performance of the system to reject a first adjacent signal. This raises concerns about a system that relies only upon a first adjacent canceller to avoid interference and lends more credibility to a Multi-streaming PAC approach.

## Performances in AWGN

In this test we used the desired signal AM IBOC exciter and the NOISE/COM generator. The level of the desired signal was set to -60dBm. The following table present the FER for each one of the three streams for different signal to noise ratio. The results are off by 1dB from what was predicted in system simulation. The core stream requires an additional 2 to 3 dB margin compared to the left and right streams

| S/N [dBm] | FER [%] | | |
|---|---|---|---|
| | Core | Left - Enh. | Right- Enh. |
| 32 | 0 | 0 | 0 |
| 31 | 0.94 | 0 | 0 |
| 30 | 8.2 | 0 | 0 |
| 29 | 52 | 0.02 | 0 |
| 28 | 97 | 0.7 | 0.04 |
| 27 | 100 | 19 | 17 |

*Table J-1: AM Hybrid Performance with AWGN*

## Receiver Sensitivity

In this test we used the desired signal AM IBOC exciter from the test set-up. The signal level was reduced using the attenuator until it reached the 1% FER. Table J-2 presents the FER for each of the three streams. The core stream requires an additional 2 to 3 dB compared to the left and right streams,

| Signal level [dB] | FER [%] | | |
|---|---|---|---|
| | Core | Left - Enh. | Right- Enh. |
| -90 | 0 | 0 | 0 |
| -91 | 0.01 | 0 | 0 |
| -92 | 1 | 0 | 0 |
| -93 | 14 | 0 | 0 |
| -94 | 71 | 0 | 0.06 |
| -95 | 99 | 1.7 | 1.27 |

*Table J-2: Receiver sensitivity*

## Co-Channel AM IBOC Interference

In this test we used two AM IBOC exciters, one is the desired signal and the second was used as the AM IBOC co-channel interference. The frequency offset between the two exciters was set to zero and we used two different I/Q generators. The RF level of the desired signal was set to -40dBm. The same audio cut was used for the desired signal with 100% modulation index. The following Table J-3 presents the results of this test in terms of D/U in dB and FER.

| D/U | FER [%] | | |
|---|---|---|---|
| | Core | Left - Enh. | Right- Enh. |
| 28 | 0.39 | 0 | 0 |
| 27 | 0.88 | 0 | 0 |
| 26 | 3.6 | 0 | 0 |
| 25 | 11 | 0 | 0 |
| 23 | 72 | 0.06 | 0.1 |
| 21 | 99 | 5.1 | 4.7 |

*Table J-3: AM IBOC Co-channel Interference*

## Dual First Adjacent analog Interference

In this test we use all three exciters. The desired AM IBOC exciter was set to the standard setting analog audio with 100%modulation and RF level at -40dBm. The other two exciters are used in the analog only signal and are set at the first upper and lower adjacent channels. The bandwidth of both analog signals is limited to +/- 4.5 kHz. The same level of interference is used in both the upper and lower channel. From the Multi-streaming PAC approach, the performance with one or two analog interference is the same to the relevant stream. Table J-4 presents the results of this test in terms of D/U and FER.

| D/U Lower First Adj.[dB] | D/U Upper First Adj.[dB] | FER [%] | | |
|---|---|---|---|---|
| | | Core | Left - Enh | Right- Enh |
| 7 | 7 | 0 | 0 | 0 |
| 6 | 6 | 0 | 0 | 0.1 |
| 5 | 5 | 0 | 0 | 1 |
| 4 | 4 | 0 | 1.34 | 11 |
| 3 | 3 | 0 | 11 | 42 |
| 2 | 2 | 0 | 29 | 79 |

*Table J-4: Performances with upper and lower analog first adjacent interference*

## Dual AM IBOC first adjacent Interferencers

In this test all three exciters were used in their full AM Hybrid capacity. An index of modulation of 100% was used in all three exciters for the analog signal. The level of the desired signal was set to -40dBm. Unlike the previous test all three streams are affected by the two IBOC interference. As in the previous test we use the same level of

interference for both interference. Table J-5 presents performance in terms of FER and D/U.

| D/U Lower First Adj. [dB] | D/U Upper First Adj.[dB] | FER [%] | | |
|---|---|---|---|---|
| | | Core | Left - Enh | Right-Enh |
| 22 | 22 | 0 | 0 | 0 |
| 21 | 21 | 0 | 0.12 | 0.18 |
| 20 | 20 | 0 | 4.2 | 4.5 |
| 19 | 19 | 0 | 37 | 62 |
| 18 | 18 | .49 | 90 | 99 |
| 17 | 17 | 7.5 | 99 | 100 |

*Table J-5: Performance with upper and lower **first adjacent AM IBOC Interference***

## Performances with upper first and second adjacent interference

In this test we used all three exciters. The desired exciter was at its standard setting, the second exciters was set in an analog only mode and set as upper first adjacent interference frequency. The third exciter was used as an upper second adjacent AM IBOC interference at the same spectral side as the first adjacent. The purpose of this test is to test how the first adjacent canceler work in the presence of same side second adjacent. The level of the desired signal was -40dBm, the level of the second adjacent signal was kept fixed while changing the first adjacent level until we got 1% error at the upper enhancement stream. Table J-6 presents performance in terms of FER and D/U.

Improved Conditions

| D/U upper sec. Adj Am IBOC [dB] | D/U Upper First Adj. Analog [dB] | FER [%] | | |
|---|---|---|---|---|
| | | Core | Left Enh | Right enh |
| 0 | 17 | 0 | 96 | 0 |
| 0 | 20 | 0 | 25 | 0 |
| 0 | 21 | 0 | 6.4 | 0 |
| 0 | 23 | 0 | 0.32 | 0 |
| 10 | 15 | 0 | 81 | 0 |
| 10 | 16 | 0 | 39 | 0 |
| 10 | 17 | 0 | 15 | 0 |
| 10 | 20 | 0 | 1.6 | 0 |
| 20 | 3 | 0 | 6.5 | 0 |
| 20 | 6 | 0 | 0 | 0 |
| 20 | 8 | 0 | 0 | 0 |

*Table J-6 -Performances in presence of upper first analog and upper second AM IBOC*

## Summary and Conclusions

Performance results presented in this section lead us to the following conclusions:

1) LDR's AM Hybrid design will provide very good digital coverage with high audio quality without interference when compared to performance of average existing AM receivers (-92dBm). Co-channel AM IBOC interference doesn't limit digital coverage in the protected contour in all scenarios of interference.

2) Analog first adjacent interference does not limit the digital coverage in the protected contour even with dual high level analog first adjacent interference.
Dual first adjacent AM IBOC interference limits significantly the digital coverage area, the receiver in this case will switch to analog.

3) The most critical result is that with same side dual first and second adjacent interferers, a relatively low level of second adjacent interference will limit significantly the performances of the first adjacent canceler. In this scenario the digital coverage is still not limited in LDR's design due to the Multi-streaming PAC approach. In this case digital coverage is not affected due to the core and the second enhancement. The quality of the audio will be slightly reduced due to the loss of the second enhancement. This graceful degradation of the digital signal under high level of interference is one of the main attributes of the Multi-streaming PAC approach.

K

# APPENDIX K

## CD CONTENTS

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CD CONTENTS:

CUT #

1. LDR subjective test audio cuts: 16 bit @ 44.1kS/s, stereo (2:46) See Appendix B for a description of test cut sources
2. silence (0:06)
3. LDR subjective test audio cuts: clear channel FM (2:46) See Appendix B for a description of FM processing
4. silence (0:06)
5. LDR subjective test audio cuts: Multi-streaming PAC @ 128kbps
6. silence (0.06)
7. LDR subjective test audio cuts: Multi-streaming PAC @ 64kbps
8. silence (0:06)
9. LDR Field Test Audio Sampler (16:00)
   The audio contained in this track was recorded during field-testing of LDR's FM Hybrid prototype receivers. The selections within this track demonstrate performance of Multi-streaming PAC at 128 kbps during RF channel conditions including:
   - Moderate to severe multipath at vehicle speeds from 0 to 60 MPH
   - Moderate to severe 1st adjacent channel interference

   The recording includes FM Hybrid audio received from WBJB-FM, Lincroft, NJ and WPST-FM, Trenton, NJ.

Attachment A

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